

SELF-PROPELLED IMAGING SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to medical imaging systems, and particularly to a self-propelled imaging system, suitable for imaging body lumens, such as the gastrointestinal (GI) tract.

BACKGROUND OF THE INVENTION

Many imaging devices are known for producing medical images of body lumens, such as the gastrointestinal (GI) tract. For example, endoscopy is widely used for observing, photographing tissue, and taking specimens from lesions and the like. In a conventional method of examining a colon using an endoscope, for example, the endoscope is typically manually inserted into the colon. In this manual technique, patients may often complain of abdominal pain and distention because the colon is extended or excessively dilated, thereby necessitating stopping the endoscopic procedure. Furthermore, it is not unusual for the colon to bleed and be accidentally perforated. Insertion of an endoscope through the sigmoid colon and into the descending colon, or through the splenic flexure, the transverse colon, the hepatic flexure or parts affected by previous operations may also be accompanied with difficulty. Because of these reasons, a colonoscopy is typically performed by a relatively few number of skilled practitioners, and the rate of patient pain and discomfort is high.

US Patent 5,337,732 to Grundfest et al. describes a robot for performing endoscopic procedures, which includes a plurality of segments attached to each other through an articulated joint. Actuators can move the segments together and apart and change their angular orientation to allow the robot to move in an inchworm or snake-like fashion through a cavity or lumen within a patient. Inflatable balloons around the segments inflate to brace a temporarily stationary segment against the lumen walls while other segments move. A compressed gas line attached to the back segment provides compressed gas to inflate the balloons and optionally to drive the actuators. The lead segment includes a television camera and biopsy arm or other sensors and surgical instruments.

SUMMARY OF THE INVENTION

The present invention seeks to provide an improved imaging system which is self-propelled, suitable for imaging body lumens, such as the gastrointestinal (GI) tract. The imaging system of the invention may be sterile and disposable, and may be manufactured

at very low cost. The system causes virtually no pain to the patient, being of very low friction and providing maximum comfort and flexibility. The system provides excellent visibility and full movement control.

The imaging system of the present invention may comprise an imaging device assembled on a carrier. First and second outwardly expandable elements may be mounted on the carrier. The second expandable element may be expanded both radially and axially. In one mode of operation, in accordance with an embodiment of the invention, during expansion of the second expandable element, obstruction of the radial expansion of the second expandable element (such as when the second expandable element presses against the inner wall of a body lumen) causes the axial expansion of the second expandable element to propel the carrier and the imaging device axially, as is described more in detail hereinbelow. The imaging system may thus self-propel distally into the body lumen without any need for knowing the local diameter of the body lumen. Other embodiments are also described hereinbelow.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

Fig. 1A is a simplified pictorial and cut-away illustration of an imaging system, constructed and operative in accordance with an embodiment of the present invention, in a contracted orientation;

Fig. 1B is a simplified pictorial illustration of a distal end of the imaging system of Fig. 1A;

Fig. 1C is a simplified sectional illustration of the imaging system of Fig. 1A;

Figs. 1D-1G are simplified pictorial illustrations of the imaging system of Fig. 1A, showing four steps of a mode of operation thereof, wherein in Fig. 1D a proximal expandable element and a distal expandable element are both contracted, in Fig. 1E the proximal expandable element expands generally spherically, in Fig. 1F the distal and proximal expandable elements are both expanded, and in Fig. 1G the distal expandable element is expanded while the proximal expandable element is contracted;

Fig. 2 is a simplified side-view illustration of the imaging system of Fig. 1A inserted in a body lumen in a contracted orientation, prior to self-propulsion therethrough, in accordance with an embodiment of the present invention;

Fig. 3 is a simplified side-view illustration of the imaging system of Fig. 1A with the proximal expandable element partially expanded and not yet touching the inner wall of the body lumen;

Fig. 4 is a simplified side-view illustration of the imaging system of Fig. 1A with the proximal expandable element further expanded and touching the inner wall of the body lumen;

Fig. 5 is a simplified side-view illustration of the imaging system of Fig. 1A with the proximal expandable element further expanded, pressing against the inner wall of the body lumen, and propelling the imaging system distally through the body lumen;

Fig. 6 is a simplified pictorial and cut-away illustration of the imaging system of Fig. 1A in the orientation of Fig. 4 or 5;

Fig. 7 is a simplified pictorial and cut-away illustration of the imaging system of Fig. 1A with the proximal expandable element expanded and a distal expandable element also expanded, in accordance with an embodiment of the present invention;

Fig. 8 is a simplified pictorial and cut-away illustration of the imaging system of Fig. 1A with the proximal expandable element contracted and the distal expandable element expanded, in accordance with an embodiment of the present invention;

Figs. 9 and 10 are simplified pictorial and cut-away illustrations, respectively, of an imaging system, constructed and operative in accordance with another embodiment of the present invention, comprising an expandable element mounted on a carrier;

Figs. 11 and 12 are simplified pictorial and side-view sectional illustrations, respectively, of the imaging system of Figs. 9 and 10, with the expandable element extended distally relative to the carrier;

Fig. 13 is a simplified pictorial illustration of an imaging system, constructed and operative in accordance with another embodiment of the present invention, comprising a jet-action head mounted on a carrier;

Figs. 14-16 are simplified pictorial illustrations of an imaging system, constructed and operative in accordance with yet another embodiment of the present invention, comprising traction members extending from a carrier, wherein in the embodiment illustrated in Fig. 14, the traction members have a helical shape, in Fig. 15, the traction members extend towards a proximal end of the carrier, and in Fig. 16, the traction members extend towards a distal end of the carrier; and

Fig. 17 is a simplified pictorial illustration of an imaging system, constructed and operative in accordance with still another embodiment of the present invention,

comprising a percussion device mounted on a carrier.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference is now made to Fig. 1A, which illustrates an imaging system 10, constructed and operative in accordance with an embodiment of the present invention.

Imaging system 10 may comprise first and second outwardly expandable elements 12 and 14. One of the outwardly expandable elements may be the proximal element and the other one may be the distal element. For example, in terms of the explanation that follows with reference to Figs. 2-8, first element 12 is the distal element that enters the body lumen first, and second element 14 is the proximal element that enters the body lumen last.

In accordance with an embodiment of the present invention, first and second expandable elements 12 and 14 expand to different shapes. First expandable element 12 may expand substantially radially with negligible axial expansion. In contrast, second expandable element 14 may expand both radially and axially, such as expanding generally spherically.

First and second expandable elements 12 and 14 may be mounted coaxially on a carrier 16. Carrier 16 may be made of any suitable, flexible, medically approved material, and may take the form of a tube. The expandable elements 12 and 14 may comprise full circumference or partial circumference elements.

Each expandable element 12 or 14 may comprise an inflatable, elastomeric tubular element formed with annular rings 18. Each expandable element 12 or 14 may be mounted in a pair of collar elements 20, wherein the annular rings 18 are received in annular grooves 22 formed in collar elements 20. Annular ring 18 may be held in groove 22 by means of an annular fastener 21, which snaps together with tongues 19 axially protruding from collar element 20. Collar elements 20 may be formed separately for each expandable element, and may be adjoined together by snapping together or by means of fasteners or any other suitable method. Alternatively, a single collar element 20 may be placed between first and second expandable elements 12 and 14, wherein the single collar element 20 has two sets of annular grooves 22 to receive therein the proximal annular ring 18 of the distal expandable element 12 and the distal annular ring 18 of the proximal expandable element 14. The collar elements 20 may be flexible and resilient to permit passage of imaging system 10 through folds of the GI tract. An O-ring 23 may slidably seal the most proximal collar element 20 with respect to carrier 16. Accordingly, the collar elements 20 at the ends of first expandable element 12 may be fixed axially with

respect to carrier 16, thereby preventing first expandable element 12 from expanding axially. In contrast, second expandable element 14 may slide axially relative to carrier 16.

In accordance with another embodiment of the invention, whether or not the collar elements 20 are fixed axially with respect to carrier 16 may be selectable. In this manner, a user may select which of the expandable elements may expand only radially and which may expand both radially and axially. For example, first expandable element 12 may expand both radially and axially, if desired, instead of second expandable element 14, which may cause imaging system 10 to move in a proximal direction instead of a distal direction.

Carrier 16 may be formed with a distal aperture 24 and a proximal aperture 26. A first supply tube 28 may be introduced through carrier 16 in fluid communication with distal aperture 24. Similarly, a second supply tube 30 may be introduced through carrier 16 in fluid communication with proximal aperture 26. First expandable element 12 may be expanded outwards by introducing therein a fluid, such as but not limited to, air or water, by means of first supply tube 28 via distal aperture 24. Likewise, second expandable element 14 may be expanded outwards by introducing therein a fluid (which may or may not be the same fluid used to expand first expandable element 12), by means of second supply tube 30 via proximal aperture 26.

Reference is now made to Figs. 1B and 1C. An imaging device 32, such as but not limited to, a CCD (charge coupled device) or CMOS (complementary metal oxide semiconductor) camera, may be mounted at a distal end of imaging system 10. For example, imaging device 32 may be mounted in the most distal collar element 20, which may be formed with a viewing window 34 through which images may be captured. Imaging device 32 and viewing window 34 may be oriented for capturing images either axially or radially with respect to carrier 16. A light source 36 may be provided for imaging device 32, wherein electrical wiring and/or optic fibers 38 (Fig. 1C) may be fed through carrier 16 to imaging device 32 and light source 36.

Imaging device 32 may be connected to an imaging processor (not shown) by optical fibers. A control system (not shown) may be provided that oversees and controls the expansion/contraction of the expandable elements 12 and 14, and other functions of imaging system 10, such as but not limited to, the timing and amount of the expansion/contraction of the expandable elements 12 and 14.

Other tubes or passageways may be provided for other functionalities. For example, a suction tube 40 (Fig. 1B) may be provided for sucking debris or other

material. A tool lumen 42 may be provided for introducing therethrough mechanical devices and/or sensors (not shown), such as but not limited to, cutting devices for cutting and collecting materials for biopsies and the like, and biosensors. Additionally, passageways 44 may be provided for passing therethrough control wires 46 for directing the imaging system 10 through tight bends and the like.

A guide member 50 (Fig. 1C) may be disposed at the proximal end of carrier 16. Guide member 50 may be funnel-shaped, for example, for comfortable placement in a rectum of a patient (not shown). A linear encoder 52 may be disposed at the proximal end of carrier 16 and pass through guide member 50. Linear encoder 52 may comprise markings and the like detectable by a decoder 54 mounted on guide member 50. Decoder 54 may sense linear movement of carrier 16 with respect to linear encoder 52, which movement is described in greater detail hereinbelow.

It is noted that the electrical and optical components may be self-contained in imaging system 10, so that the entire system 10 is fully independent of external wiring. In such an embodiment, imaging system 10 may wirelessly transmit or receive data to or from an external processor (not shown).

Reference is now made to Figs. 1D-1G and Figs. 2-5, which illustrate imaging system 10 in different orientations for self-propulsion through a body lumen 60, such as but not limited to, the colon, in accordance with an embodiment of the present invention. (The body lumen 60 is omitted in Figs. 1D-1G for clarity.)

In the initial orientation of Figs. 1D and 2, none of the expandable elements 12 and 14 are expanded, as in Fig. 1A. In this contracted orientation, imaging system 10 may be inserted in body lumen 60. In Fig. 3, second (proximal) expandable element 14 may be expanded outwardly. As seen in Fig. 3, before the proximal expandable element 14 touches the inner wall of body lumen 60, it may expand both radially and axially (e.g., spherically). O-ring 23 slides proximally along carrier 16, as indicated by arrow 53, with the result that carrier 16 (along with imaging device 32) does not yet advance in body lumen 60.

In Fig. 4, the proximal expandable element 14 has expanded sufficiently so that it touches the inner wall of body lumen 60. Carrier 16 (along with imaging device 32) has still not advanced in body lumen 60, and O-ring 23 has continued to slide proximally along carrier 16, as indicated by arrow 53. The orientation of Fig. 4 is shown pictorially in Fig. 6.

In Fig. 5, the proximal expandable element 14 continues to expand. Since the proximal expandable element 14 has already contacted the inner wall of body lumen 60, the continued expansion of expandable element 14 presses it against the inner wall of body lumen 60. The friction between expandable element 14 and the inner wall resists the radial expansion, with the result that most of the expansion of the proximal expandable element 14 is in the axial direction, as indicated by double arrow 57. This causes carrier 16 (along with imaging device 32) to advance distally in body lumen 60, as indicated by arrow 62, by a distance δ in Fig. 5. The distal advancement of carrier 16 relative to guide member 50 may be detected by linear encoder 52 and decoder 54 (seen also in Fig. 1E).

Thus the expansion of second expandable element 14 may advance the carrier 16 distally in body lumen 60, without any need for sensing when second expandable element 14 has actually contacted the inner wall of body lumen 60. Rather once second expandable element 14 presses against the inner wall of body lumen 60, further expansion of second expandable element 14 may advance the carrier 16 distally in body lumen 60. The control system may control the further expansion of second expandable element 14 in order to control the amount of incremental advancement of carrier 16 and imaging device 32.

In Figs. 1F and 7, first (distal) expandable element 12 may be expanded radially. Both first and second expandable elements 12 and 14 now press against the inner wall of body lumen 60 (not shown in Fig. 7) and fix imaging system 10 in place in lumen 60. In Figs. 1G and 8, second expandable element 14 may be contracted inwardly (e.g., deflated) so that it no longer presses against the inner wall of body lumen 60 (not shown in Fig. 8). Images may be captured by imaging device 32 at either of the orientations shown in Figs. 7 and 8. As seen best in Fig. 1G, second expandable element 14 advances distally along carrier 16 when it is contracted inwardly, as indicated by arrow 67.

In order to advance carrier 16 further distally, first expandable element 12 may be contracted so that imaging system 10 returns to the contracted orientation of Fig. 2, and the operating cycle may be repeated to incrementally advance imaging system 10 through body lumen 60. The user or control system may ensure that carrier 16 does not move back proximally at each incremental distal advance. Alternatively, as another way of ensuring that carrier 16 does not move back proximally at each incremental distal advance, first expandable element 12 may initially remain expanded against the inner wall of body lumen 60 while re-expanding second expandable element 14, and then first expandable element 12 may be contracted so as not to impede the incremental distal advancement

caused by the re-expansion of second expandable element 14. The control system may control the timing of the contraction of the first expandable element 12 and the expansion of the second expandable element 14.

Imaging system 10 may be contracted to the orientation of Fig. 2 for removal from body lumen 60.

Reference is now made to Figs. 9-12, which illustrate an imaging system 70, constructed and operative in accordance with an embodiment of the present invention.

Imaging system 70 may comprise a carrier 72, such as in the form of a tube, to which a stopper 74 is mounted at a distal portion thereof. An expandable element 82 may be at a distal portion of carrier 72 in fluid communication with a fluid source (not shown) via one or more apertures 80. Expandable element 82 and carrier 72 may comprise an elastic, flexible member folded into itself, wherein the expandable element 82 is at the distal end and the carrier 72 extends proximally therefrom. An O-ring 78 may seal expandable element 82 with respect to the rest of carrier 72 (Fig. 12). Fluid 79 may flow through aperture 80 to at least partially fill expandable element 82 (Fig. 12). Expandable element 82 may comprise a flexible sleeve, such as a sleeve made of an elastomeric material (e.g., rubber, latex, etc.).

Imaging system 70 may be inserted in a body lumen, e.g., rectum of a patient (not shown), wherein stopper 74 abuts against the anus (not shown). Fluid 79 may then be introduced via aperture 80 to at least partially fill the flexible sleeve, thereby expanding expandable element 82 relative to carrier 72 and further into the colon (not shown). The portion of carrier 72 proximal to stopper 74 may be drawn distally into the colon by the expansion of expandable element 82. Carrier 72 may have a lumen 76 for passage therethrough of an instrument 84, such as but not limited to, imaging devices (e.g., camera, x-ray imaging device), illumination devices, biopsy collecting tools, optical devices, fluid devices, etc. The instrument 84 may pass all the way through lumen 76 and through a distal aperture 73. In this manner, for example, an imaging device may be introduced through carrier 72 to provide images of the colon.

Reference is now made to Fig. 13, which illustrates an imaging system 90, constructed and operative in accordance with another embodiment of the present invention.

Imaging system 90 may comprise a carrier 92, such as in the form of a tube, comprising a fluid passageway 93 for passage of a fluid 94 (liquid or gas) therethrough. A jet-action head 95 may be mounted on a distal end 91 of carrier 92. Jet-action head 95

may be formed with fluid jet outlets 96 facing a proximal end of carrier 92, which are in fluid communication with fluid passageway 93. An imaging device 97 may be disposed in jet-action head 95. As mentioned similarly above, imaging device 97 may comprise, without limitation, illumination devices, biopsy devices, other tools, etc. Imaging device 97 may comprise a camera, in which case jet-action head 95 is preferably transparent. Imaging device 97 may alternatively comprise an x-ray imaging device, for example.

Imaging system 90 may be inserted in a rectum of a patient (not shown), and fluid 94 introduced in fluid passageway 93 (from a fluid source, not shown) exits fluid jet outlets 96 to propel imaging system 90 in the body lumen, e.g., colon (not shown).

Jet-action head 95 may be expandable and contractible, such as made of an elastomeric material. Alternatively, jet-action head 95 may be made of a rigid material, such as but not limited to, plastic or metal. Jet-action head 95 may comprise a magnet 98 for attaching to an imaging device (capsule or bolus) in the gastrointestinal tract (not shown). Any of the other embodiments of the present invention may also comprise a magnet like magnet 98.

Reference is now made to Figs. 14-16, which illustrate an imaging system 100, constructed and operative in accordance with another embodiment of the present invention. Imaging system 100 may comprise a carrier 102, such as in the form of a tube, which comprises one or more traction members 104. Traction member 104 may comprise a loop 106 extending from carrier 102. An actuator 108 may be in operative communication with traction member 104. Actuator 108 may comprise, without limitation, a servomotor, gear motor, step motor and the like.

In the embodiment illustrated in Fig. 14, loop 106 may have a helical shape that at least partially corkscrews around a periphery of carrier 102. In the embodiment illustrated in Fig. 15, loop 106 protrudes from a side of carrier 102 and extends towards a proximal end 109 of carrier 102. In the embodiment illustrated in Fig. 16, loop 106 protrudes from a side of carrier 102 and extends towards a distal end 111 of carrier 102. It is appreciated that these are just some examples of possible loops and the invention is not limited to these examples. The traction members 104 may be provided in any amount, size and shape.

Actuator 108 may move loop 106 relative to carrier 102. For example, in the illustrated embodiments, loop 106 may be rotated about its own axis (as indicated by arrows 112). Alternatively, as indicated by arrows 114 in Figs. 15 and 16, loops 106 may be rotated like the track of a tracked vehicle. The rotational movement of loops 106

against the inner wall of the body lumen, e.g., colon (not shown), propels and advances imaging system 100 through the colon. To increase traction and friction against the lumen walls, loop 106 may be expandable and contractible, such as by means of a fluid introduced therein through appropriate fluid passageways (not shown) in carrier 102, as similarly described hereinabove for the embodiment of Figs. 9-12. The expansion of loop 106 may improve the field of view for imaging. It is noted that in any of the embodiments of the invention, components may be inflated to improve the view for imaging.

An imaging device 116 (seen in the embodiment of Fig. 16) may be disposed in carrier 102. Imaging device 116 may comprise a camera, in which case the distal end of carrier 102 is preferably transparent. Imaging device 116 may alternatively comprise an x-ray imaging device.

It is noted that in any of the embodiments of the invention, the components of the system may be energized by an internal or external power source, and may comprise a transmitter and/ or receiver to an external device. It is further noted that in any of the embodiments of the invention, the elements that move in the body lumen may be shaped or may comprise structure that preferentially facilitate movement in one direction (e.g., in the distal direction) as opposed to the opposite direction (e.g., in the proximal direction). Such structure may comprise, without limitation, inflatable protrusions or spurs, which when deflated or contracted, permit movement in the opposite direction (e.g., in the proximal direction).

Reference is now made to Fig. 17, which illustrates an imaging system 120, constructed and operative in accordance with another embodiment of the present invention.

Imaging system 120 may comprise a carrier 122, such as in the form of a tube. A percussion device 124 may be mounted on a distal portion of carrier 122. Percussion device 124 may comprise, without limitation, a vibrator, an oscillator, a solenoid device, a pneumatic, hydraulic, or electromechanical hammering device and the like. Percussion device 124 may contain its own power source (e.g., battery) or may be operated by an external actuator (not shown). Oscillation or vibration of percussion device 124, indicated by arrows 126, against the inner wall of the body lumen, e.g., colon (not shown), propels and advances imaging system 120 through the colon. An imaging device 128 may be disposed in the distal portion of carrier 122. Imaging device 128 may comprise a camera, in which case the distal end of carrier 122 is preferably transparent. Imaging device 128 may alternatively comprise an x-ray imaging device.

In the embodiment of Fig. 17, it is possible to use carrier 122 as a guide member or wire for a catheter-like procedure (as similarly used in angioplasty procedures), wherein an instrument may be introduced in or over carrier 122. For example, an outer catheter 129 may be slipped over carrier 122. An instrument 127 may be introduced over carrier 122, on either side of percussion device 124, and may be pushed distally by any suitable means. As similarly described hereinabove with instrument 84, the instrument 127 that may be introduced in or over carrier 122 may comprise, without limitation, a torus-shaped camera (CCD) or other imaging device (e.g., x-ray imaging device), illumination device, biopsy collecting tool, optical device, fluid device, etc.

It will be appreciated by person skilled in the art that the present invention is not limited by what has been particularly shown and described herein above. Rather the scope of the present invention is defined only by the claims that follow: